Review on studies of *Eupatorium adenophorum*--an important invasive species in China

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Abstract: *Eupatorium adenophorum* Spreng. was introduced in Yunnan Province of China around 1940. Since then it has been spreading rapidly, particularly in the southern and southwestern parts of China and caused serious economic loss. The biological research and integrated control on *E. adenophorum* were carried out from 1980's in Yunnan Province. Together with other 15 invasive external species, the weed has been listed in the White Paper by The State Environmental Protection Administration of China. This paper briefly reviews the studies on natural distribution, biological character, ecological character, chemical component, hazard, potential application and the control of *E. adenophorum*. The research direction for this invasive external species in future was also discussed.

Keywords: *Eupatorium adenophorum;* Crofton weed; Invasive species; Biological character; Integrated control; Natural distribution; Hazards; China

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Introduction

A growing number of invasive external species are causing significant economic and environmental impacts in China. These species include microbial pathogens, nematodes, insects, crustaceans, mollusks, fish, birds, mammals, and vascular plants. A few important invasive external species cost ¥57.4 billion yuan annually (Ma *et al*, 2003). Crofton weed (*Eupatorium adenophorum* Spreng.) belongs to the Asteraceae family and there are 600 species in Eupatorium genus, which mainly distribute in tropical zone and temperate zone of Central America, and 14 species and a few varieties distribute in China, of which 3 species has been naturalized in China. Crofton weed is perennial herbaceous species and native to the regions from Mexico to Costarica. It was introduced into Europe first and then into Australia and Asian as ornamental plant. Crofton weed has been reported to cause thereat to many countries such as America, Australia, New Zealand, South Africa, Spain, India, Philippine, Malaysia, Singapore, Indonisea, Papua new guinea, Thailand, Burma, Vietnam, China, Nepal, Pakistan and pacific archipelago (Auld 1966; Kluge, 1991.) It occurs within the areas at 37°North latitude to 35°South latitude.

This paper summarized the studies on Crofton weed in China.

Distribution of *E. adenophorum* in China

In the 1940s, *E. adenophorum* spreads by nature into Yunnan Province of China. Nowadays, it grows commonly in Southwestern China, including Yunnan, Guizhou, Xizang (Tibet), Guangxi, Sichuan, Taiwan, Hubei provinces and Chongqing Municipality.

Monica Papes (2003) predicated the distribution of *E. adenophorum* in China with GAPR model that is based on the ecological characteristics of known occurrences on the native distribution of a species. The best prediction of the native distribution of Crofton weed was obtained using four factors: diurnal temperature range, wet days, elevation, and slope. The result shows that the eastern part of China was in general predicted as more suitable for invasion than the western part. More or less continuous with the areas currently occupied to the north, are six provinces that appear to be directly vulnerable: Gansu, Ningxia, Shaanxi, Shanxi, Henan, and Hubei. In addition, the model also detected four potential distributional areas that are disjunct from the present distribution, in which this species could establish if it is introduced. The four potential distribution areas include Liaoning and Heilongjiang Provinces in the northeast and Fujian and Zhejiang provinces in the southeast (Monica Papes 2003).

Crofton weed distributes uprightly. It breaks out severely within the elevation range of 1300–2200 m in Sichuan Province but scattered in wet soil below elevation 1300 m. It distributes in lawn, shade and wet areas fringing forests, and along roadsides within the elevation of 2200–2500 m. With ascend of elevation, the distribution area of Crofton weed decrease and growth vigor becomes weak.

Occurrence of Crofton weed is frequently associated with precipitation, fertile soil, solar radiation, and temperature range. Population colonization starts in optimum habitat of low elevation, then disperse radially. Crofton weed occurs mainly in overgrazed pastures, abandoned field, cut-over land, coppice shoot, field border, and residence around and mainly distributes on both sides of railway, road, stream and river, valley (Zhou *et al.* 2004).

Biological character

Crofton weed is a shrubby perennial with a woody rootstock and numerous upright branching stems. This kind of weed is shallow-root herb with funicular root. It is usually 0.8 to 2.5 m in height. Young stems are soft and establish roots wherever they touch to the ground. The leaves are in opposite pairs, bright

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green, trowel-shaped, 60-70 mm long, 45 mm broad with the edges toothed. Flowers are white, in small, dense heads at the ends of the branches. Its Seed is slender, angular, 2 mm long, almost black, with fine white hairs at the tip. The weight of per thousand seeds is 0.04-0.045 g (Zhou *et al* 2004).

Crofton weed is plant of C_3 type and sun inclining to shade. Its wide adaptive range, low light compensation point and high photosynthetic rate retain long time of a year. The individual life history of Crofton weed can be divided into four phases: 1–2 years as juvenile stage, 3–6 years as adolescent stage, 7–11 years as mature stage, and 12–15 years as senescence stage. It reproduces itself by seeds in all stages among which adolescent stage contributes the most seeds. According to investigation, over 90% seeds locate in surface soil of 5 mm. Crofton weed has very strong reproduction capacity and its regularity is similar to sexual propagation. Crofton weed usually buds in January and flowers from the end of February on. Population flower phase is long. Crofton weed can produce triploid seeds by agamic reproduction. Light is critical for phase of seed germination while its shade tolerance of seedling is very strong. Only for 6 months can Crofton weed seedling turn half woody plant. Woody seedling can tolerate cold, drought and heat, which are in favor of invading other communities.

Ecological study

Light duration and light spectrum have effect on seeds germination of Crofton weed. Seed germination rate reaches the highest point in glow and the lowest point in blue light and increases with prolonging of light when light duration is over 48 h. Seedling growth is markedly controlled by light intensity. The seedling is even caused to lethality when the light intensity is below 10% full sunlight.

The colonization, propagation, dispersal, and outbreak of Crofton weed have close correlation with temperature and humidity. Crofton weed grows well under the conditions that mean annual temperature is over 10℃, mean annual humidity over 68%, absolute minimum temperature over –11.5℃, the maximum temperature is below 35℃, and the mean lowest temperature is over 6℃. Elevation also has effect on the distribution of Crofton weed by climatic variation with elevation height (Meng *et al.* 2003).

Crofton weed does not have strict selectivity for soil type. The population number and growth vigor of Crofton weed reach a high level when soil contains much nitrogen. The experiment shows that there is marked difference in increase rates of the plant with variable fertile soil. The best growth for Croften weed with luxuriated branches was found at the most fertile soil (Liu *et al.* 1988).

The occurrence of Crofton weed has positive correlation to biodiversity inner community and passive correlation to distance from plough. According to the investigation in Sichuan Province, we draw the spatial map of population distribution. Distribution pattern will has effect on the distribution pattern of released *Procecidochares utilis.* It is concluded that the spatial distribution pattern of Crofton weed's population mainly obeys Neymen distribution of the clumped distribution. In order to characterize the age structure and dynamics of the Crofton weed's population so as to control its hazard, we investigated 20 plots (10 m×10 m) in Panzhihua, Sichuan Province of China. The research on the age structure of 4 populations showed that most individuals were within the scope of infancy period (92.32%) and youth period (6.40%) at present. The analysis of life tables and survival curves showed that chronological sequence for Crofton weed invasion is as follows: roadside fields →the margin of broad-leaf forest→broad-leaf forest→*Pinus yunnanensis* forest. Even under different environmental conditions, survival curves of Crofton weed populations belonged to Deevey type III, and death peaks of different populations were in the period of 1–2years old when the mortality rate was up to 97.30%. The degree of populations tallying with the typical curves relates to the intensity of human disturbance. In general, the mortality of Crofton weed is as high as 93.07% in infancy period and 92% in mature period is high. The prediction models of time sequence for different populations of Crofton weed after 3, 5 years indicated that young and mature individuals will dominate the populations. Therefore, the hazard caused by Crofton weed in Panzhihua will be serious in 3 or 5 years (Sun *et al.* 2004).

Chemical components of Crofton weed

Study on chemical components and biological character of Crofton weed can provide chemical foundation for discovering this weed interaction with other plants and animals. In addition, we can extract compound with bioactivity to produce biological agent. Xu *et al.* (1988) isolated 13 compounds such as n-dotriacontane, β-sitosterol, stigmasterol, taraxasteryl palmitate, taraxasteryl acetate from Crofton weed. Ding *et al.* (1999) isolated a new sesquiterpenene lactone-eupqtoranolide and 11 known compounds from the flowers of Crofton weed.

The experiment on effect of water extract of Crofton weed on other seeds germination was conducted. The result shows that the extract from Crofton weed could promote seeds germination of *Pinus yunnanensis,* while it inhibit the seeds germination of wheat, maize and white clover and its inhibiting degree has positive correlation with extract concentration (He 1990). The inhibition action of leaf water extract overruns any other parts of the plant. Moreover, water extract of Crofton weed also inhibit the germination of itself seeds and this conclusion seems accord with that of Yadav A. S (Yadav and Tripathi 1983) and that of Tripathi R S. (Tripathi 1982). They concluded that the survival rate and growth vigor of Crofton weed seedlings has passive correlation with the distance from mature plant. Crofton weed inhibit bacteria the most, and fungi take second place, but has no effect on ray-fungi (He Aijun 1990).

Hazards caused by Crofton weed

Statistics provided by the Chinese Academy of Sciences shows that Crofton weed had expanded to over 24.7 million hm^2 in Yunnan Province by the end of 1998, endangering a multitude of species there.

Crofton weed absorbs most of the nutrition in soil to support rampant expansion, at the same time, it produces a certain toxin that prevents other species from growing. Nitrogen, phosphor, kalium in soil was decreased respectively by 56%–96%, 46%–53%, 6%–33% after Crofton weed invaded for 210 days (Zhou and Xie 1999). The secretion substance of Crofton weed has allelochemics action on other plant and microorganism in soil, inhibiting seeds germination and growth of other plant.

When the plough and rotation pasture are invaded by Crofton weed, doubled labor force have to be thrown in for treating the weeds. The invasion of Crofton weed can reduce foodstuff by 3%–11%, output of mulberry leaf by 4%–8% due to the competi-

tion for water, fertile, and sun light (Ge and Jin 2003). Crofton weed inhibit and repulse honey plant and medicinal plant. If Crofton weed move into run-down pasture, stock carrying capacity can be reduced. According to investigation, only 3 years after invading into natural pasture, the coverage of Crofton weed can reach 85%–95% and reduce grass output by 70.1%–79.4% (Zhou,2004).

Once Crofton weed occupies barren hill, it prevent natural forest from growing and renovating. In case this kind of plant evade into the economic forest, it causes the growth of field crop weakened, output decreased, variety declined, even trees to death. Crofton weed not only make difficulty for artificial forestation but also form threat to tree seedlings.

Crofton weed is toxic to horses. Long term feeding on Crofton weed may lead the horses to death. .Livestock will diarrhoea, dehair, abort, even die if they eat Crofton weed. The seeds of Crofton weed have fine hairs and pollen, which may cause livestock asthma and mankind anaphylactic disease and bronchitis.

Crofton weed is a fire hazard in dry days, for it has abundant dead leaves and dry shoots. It occupies river-bed out of dates and roadside to block traffic.

Comprehensive application of Crofton weed

Biofuel

Crofton weed will give off smell to pollute environment when it is burnt. If the plant is used continuously in a normal way, it will induce a chronic poisoning of the fermentation microorganism groups and the continuous use of fermentation pools cannot be ensured. Given a preparatory treatment, a normal continuous operation is possible. We can deal with fresh plant in advance and put them into fermentation tank at some rate. The ratio of fermentation broth is 40% inocula, 6% preprocess Crofton weed and water in fermentation volume (Jiang and Yu 1986; Zhang 1996).

Biological medicine

Utilizing compound contained in Crofton weed to prevent pest and disease is a hot research in domestic or abroad. Li *et al.* (1995) reported that the extract of Crofton weed could control panoychus citri magregor. The fraction Ⅷ obtained from the chloroform extract has stronger toxicity to the cotton aphid *Aphis gossypii*. The weed extract has insecticidal action on the adults of the rice weevil, maize weevil, Chinese bean weevil, and European bean weevil. Larvae of *Pieris rapae* have antifeeding action on extract of the plant. The compounds extracted from the plant of Crofton weed can be used to treat headache, neuralgia, and sleeplessness.

Feed after detoxifying

Crofton weed is a perfect feed resource because the content of crude protein is about 20% and the content of 8 categories amino acid is high. Crofton weed cannot be used directly to feed livestock, however, the toxic compounds can be greatly degraded through treatment with compound fungus and fermentation in aerobic conditions. Nutrition does not lost and toxicity is deposed after being detoxified, which is proved by the feed experiment of poultry (Zhang 1996).

Bio-fertilizer

Crofton weed plant contains 0.372% total nitrogen, 0.062% total phosphor, and 0.580% total kalium, as well as calcium, magnesium, iron, sulfur, silicon, cuprum, zinc, manganese, boron of nutrient element. It can be used as green manure, farmyard manure, fermentation manure, and ash manure.

Producing paper and board

The weed contains much fibrin. It can be used to produce paper and board after deodorazation treatment. This technology is developed successfully in Yunnan Province.

Water and soil conservation

The outbreak of Crofton weed is associated with destruction of primary plant community, bare ground, and loose soil except its biological character. Crofton weed is advised to cover ground as the first step, then tall seedlings are used to afforest. It has positive significance in terms of water and soil conservation.

Other aspects

Crofton weed is used as compost to produce domestic fungus. Handicraftsmen in the Dali Bai Autonomous Prefecture of Yunnan Province are using Crofton weed as a major dyestuff for their traditional dyeing. Some scientists try to accomplish the producing technology of xylitol from the stem of Crofton weed by microorganism fermentation.

Control of Crofton weed

Biological control

The tephritid gall fly *Procecidochares utilis* was introduced into Hawaii from Mexico to control Crofton weed in 1945. Its biological character and its feasibility to deal with Crofton weed have been wildly studied. The plant height and bud number are reduced and sexual productivity decreased in item of *procecidochares utilis*. From the experiment in Kunming,Yunnan Province it has been concluded that Crofton weed was the only plant attacked by*procecidochares utilis*. Chen and He (1990) reported that it was optimal that one *Procecidochares utilis* holds ten shoots of Crofton weed for its releasing on field. In addition, the strategy of releasing *Procecidochares utilis* in poly-sites and one site at several times was advanced.

Alternative control way is based on the compete phenomenon among plants to control the growth of Crofton weed by occupying ecological niche with growth priority of one or more plants. Alternative control could be used in the areas for forestry and animal farming. The chosen alternatives must be easy to grow, with fast growing, and the canopy density can reach 70% within a short period and have a high economic value. We have selected successfully *Trifolium repens, Trifolium pratense, Pennisetum hydridum* to control Crofton weed. In addition, *Eucalyptus citriodora, Acacia confusa* of fast-growing tree also proved efficient control on vegetative growth and sexual propagation of Crofton weed.

Mycovellostella eupatorii-odorati (Yen) was proved to reduce photosynthetic rate, chlorophyll content, transpiration rate, total nitrogen and total phosphorus of Crofton weed. Moreover, height, leaf number and flower number of infected plants decrease obviously as compared with those of normal plant. Mycovellostella eupatorii-odorati has high specificity on host (Dodd 1961; Morris 1989). It is reported that LA-toxins could poison the leaves of Crofton weed (Ye *et al.* 2002)

At present, biological control only plays a role of slowing the

dispersal speed of Crofton weed, and could not reach the goal of eliminating completely.

Chemical control

Chemical control is suitable for single population of Crofton weed. The control result of spilling chemical remedy is influenced by season. The main compounding herbicides refer to 0.6%–0.8% solution of 2,4-D, 0.3%–0.6% 2,4-D and 2,4,5-T , 5.0% solution of chlorate sodium. Most herbicides only operate on the plant above ground while act hardly on the subterraneous root. Although some kinds of herbicides can be used to control Crofton weed effectively, the use of chemical control must be carried out wisely to avoid the possible negative effects to the environment.

Mechanical control

Tractor with can be used to control Crofton weed of single population on accessible section, while mattock can be used to dug out scattered plants of small area. Plants must be removed at once to prevent re-growth. Regular slashing will reduce flowering and seedset, moreover the vigor and density of infestation. This way cannot be applied independently because of abundant seed in soil and strong asexual propagation of the plant. In addition, the infested habit is very complex, e.g. steep slope, scattered edge of plough, sparse forest undertake. Thus, complex habitat confines mechanical control in fact.

Manual control

Manual control strategy only be used in economic plantation, e.g. tea and fruit trees which have a stricter requirement for management. In Guizhou Province, government organized farmers to dig out Crofton weed in tung forest and burn the plant, while root was bought by government. The government intents to stimulus more farms to protect economic plantation, but the price of this strategy is very high.

Integrated control

It can be concluded form above that Crofton weed cannot be perished effectively by one single way because of complex topography, climate type and big flexibility of weed itself. Once Crofton weed is cleared, the area must be planted with pasture grasses or fast-growing shrubs to provide competition against seedling re-growth. The Agriculture Ministry of China has set up experimental unit to control Crofton weed in Yunnan Province.

Discussion

The invasion of Crofton weed has been disasters by seriously suppressing native species in disturbed forests and pastures in Southwest China. It has cause high loss in terms of economy and ecological environment; more important it will spread into Central China and Eastern China unless valid measures are taken. We must set out from basal research of biology and ecology to control this weed. Focus should be emphasized on the propagation process and mechanism of population outbreak in order to locate its weakness during the growing and propagating period. We should establish and perfect the legislation systems to intensify the safety management on external invasive species that are introduced intentionally or unintentionally. In addition, international cooperation and information exchange on management should be strengthened in order to prevent and control technology of alien invasive species and to enhance national administrative capacity and expertise.

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